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# S&OP Network Model for Commodity Lumber Products

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**Abstract.** In the lumber industry, we can observe that commodity products prices fluctuate according to seasonal patterns. Nevertheless, it is believed by the industry that it is impossible to take advantage of this information for many reasons. Firstly, the fact that many different products are produced at the same time from the same material input (coproduction) makes it difficult to produce exactly and only what is needed. Secondly, equipment is already being used at 100% capacity all year long, so there is no room to increase production when product selling price increases. Finally, the belief is that keeping finished products in stock till the moment for the right price arrives would increase inventory holding cost too much. For these reasons, the typical sawmill produces using a "push" strategy and sells its production, without much consideration of yearly price fluctuation. We have developed a mathematical model that allows planning the sales and operations of a network of sawmills at the tactical level. Using that model, we were able to show it is in fact possible to modulate production and inventory levels to increase sales revenue. We generated a single plan which, if it had been used for each of the last twelve years, would have increased the gross margin generated by an average of 1,47% of sales revenue.

**Keywords**. Optimization, sales and operations planning, seasonality, supply chain, lumber, sawmill.

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# 1 INTRODUCTION

Sales and Operations Planning (S&OP) combines sales plan based on demand forecasts with production plan which determines capacity requirements, inventory and backlog levels (Olhager, Rudberg et al. 2001). It can be defined as a periodic-process tactical planning that vertically links business plans and strategic plans for the long term with operational plans in the short term, and horizontally links demand with supply chain capacities (Feng, D'Amours et al. 2008). According to APICS (2010), S&OP integrates all the business plans of a company (supply, production, sales, customers, marketing, R&D and finance) in general terms, facilitates coordination between the various functions and supports the strategic and business plans covering a planning horizon of between one and two years.

Although S&OP has shown great gains in other industries, this approach is not used in the lumber industry. We have done a study to assess the potential gain in the lumber production supply chain.

Unlike traditional manufacturing industries which have a convergent product structure (i.e., assembly), the lumber industry needs to master industry-specific operational processes. These are characterized by: (1) a divergent product structure (i.e., trees are broken down into many products), (2) the highly heterogeneous nature of its raw material and (3) radically different planning problems to be solved by each production center.

Due to the highly heterogeneous nature of the resource and the inherent complexity of forecasting production throughput, the dominant thinking in the North American lumber industry is to produce the maximum volume with the available resource. This can be identified as a push production mode, where demand from specific clients is not taken into account. Production is oriented towards large batches to take advantage of economy of scale, resulting in large inventories, low flexibility and low agility. The production manager has as main objective to feed the production line continuously, in order to maximize the production rate and throughput. He also tries to forecast the quantity of output products as precisely as possible. Once a week, he transmits to the sales department an updated forecast of what product should be available (and when) during the following four to six weeks.

In the lumber commodity market, we see a rather large price fluctuation during the year, but the products are not available in stock at the right time to take advantage of that fluctuation. The divergent product structure increases the difficulty of exploiting price fluctuation as it is not possible to produce the different products independently. Also, there is almost no flexibility in raw material replenishment, which thus limits the variation in the lumber sawing process. On the production side, the capacity is always used at 100% so there is no room to modulate the production. Moreover, current inventory levels cannot be increased as profit margin is limited. In that specific context, it seems uncertain that the yearly price fluctuation can be exploited.

We thus initiated a project with a manufacturing company of the lumber industry to assess whether there was still a potential gain in using the S&OP approach in such context. We propose a model that performs integrated sales and operations planning. We show that we are able to use all of the available capacity without increasing its actual inventory level and that we can significantly increase the revenue.

In the remainder this paper, we first present the activities involved in the lumber supply chain and then review the S&OP literature in the forest products industry. The mathematical model that we developed is described in Section 3. Section 4 is about the study we made with a company using our model.

# 2 PRELIMINARY CONCEPTS

## 2.1 Lumber supply chain

The lumber supply chain is similar to that of other industries: lumber material flows from forest contractors to sawing facilities, to value-added mills (referred to as secondary transformation), and through the many channels of distributors and wholesalers to finally reach the markets. Within the sawmill, there are three different production units involved in softwood lumber production: sawing involves the cutting of logs into various sizes of rough pieces of lumber, drying, which reduces the lumber moisture content and finishing, where lumber is planed (surfaced), trimmed and sorted. Figure 1 presents these units.

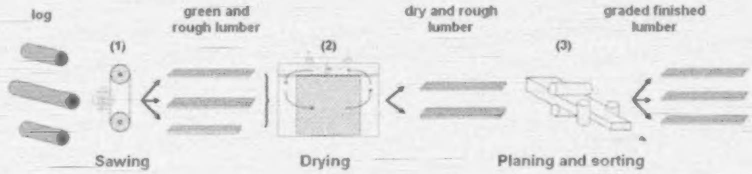


Figure 1 : Lumber supply chain.

Logs oftentimes remain in a sawmill yard for a lengthy period of time before being processed. They are stored in huge lots according to certain physical characteristics (species, length, average diameter, etc.), each lot representing a specific class of logs. At the sawing production unit, different dimensions of lumber are obtained at the same time from a single log, which is called co-production. Most of the time, sawmills share access to data regarding past production, allowing them to forecast the expected quantities of the different types of lumber to be produced from a specific quantity of logs of a given log class. This information defines a production matrix.

Softwood lumber drying is a rather complex process to carry out. It takes days and is done in batches within large kiln dryers. Bundles of lumbers of different lengths can be dried in the same batch (e.g. 8-foot and 16-foot), but lumbers must be of the same dimension and species (although there are some exceptions). Under certain circumstances, special sections of the wood yard may be used to perform air drying. Air drying, which precedes kiln drying, may take several weeks but allows the reduction of the drying time in the kiln. For a given batch of green lumber, there are different possible alternative operations that can be used for air-drying and kiln-drying.

At the finishing production unit, lumbers are first planed (or surfaced). They are then sorted according to their grade (i.e. quality) with respect to the residual moisture content and physical defects. Lumber may be trimmed in order to produce a shorter lumber of a higher grade and value. This process is usually optimized by hardware to produce products with the highest value, with no consideration for actual customer demand. This causes the production of multiple product types at the same time (co-production) from a single product type in input (divergence). It is important to note that co-production cannot be avoided from a planning point of view: it is embedded within the transformation process. It is common to obtain more than 20 different types of products from a single product. The expected products mix to be obtained from a batch depends on the drying process used. Therefore, in the planning models introduced hereafter, we consider the output product associated with each of the drying processes as a different kind of input for the finishing process.

## 2.2 Supply chain planning

Each business process involves specific planning decisions (namely what, when and how) that can be implemented from a short and a long-term perspective (Ballou, 2004). For example, a delivery plan or the update of a forecast can be executed within a week, while the selection and implementation of a particular strategy can necessitate a couple of months, or even years. This is why planning decisions are generally classified into one of three major levels: strategic, tactical and operational.

The strategic level focuses on a time horizon that is usually greater than a year and the length of the time horizon varies from one industry to another. For the forest products industry, strategic planning is very long-term. It includes the choices related to forest management strategies, silvicultural treatments, conservation areas, road construction, the opening/closing of mills, the location/acquisition of new mills, process investments, product and market development, financial and operational hedging, planning strategies and inventory location.

The tactical level involves an intermediate time horizon and focuses on tactical issues pertaining to aggregate workforce and material requirements for the coming year. In planning problems dealing with production/distribution issues, tactical planning normally addresses the allocation rules that define which unit or group of units is responsible for executing the different network activities, or what resources or group of resources will be used. It also sets the rules in terms of production/distribution lead times, lot sizing and inventory policies.

More specifically, in the lumber supply chain, tactical decision making usually deals with the challenge of integrating different activities such as bucking, sawing, drying, planing and grading processes, in the network at minimum cost. Companies are generally located at multiple sites and offer a large number of products, which contributes to the complexity of the planning problem.

The operational level is considered short-range, with decisions frequently made on an hourly or daily basis. Operational decision making is usually distributed among the different facilities, or units in the facilities. Within the production process, one type of operational planning problem deals with cutting and must be solved by many of the wood product mills (e.g., lumber, dimension parts), as well as pulp and paper mills. Scheduling the different products moving through the manufacturing lines is also a typical operational planning problem, as is process control involving real-time operational planning decisions.

For the lumber supply chain, researchers have addressed a number of issues. Donald et al. (2001) analyzed the benefits of integrating primary and secondary manufacturing. They developed two different production planning models, one for non-integrated value-added facilities and another that optimized production from the sawmill log yard through to secondary manufacturing. They demonstrated that production decisions in the value-added facility had a significant influence on production decisions in the sawmill. Integration of the two facilities yielded a 10% increase in revenue.

For timber and lumber products, Maness and Adams (1993) proposed a model integrating the bucking and sawing processes. Formulated as a mixed integer program, this model links log bucking and log sawing for a specific sawmill configuration. The proposed system can handle the raw material distribution of one sawmill over one planning period for a final product demand that is known. Maness and Norton (2002) later proposed an extension to this model capable of handling several planning periods.

Reinders (1993) developed a decision support system for the strategic, tactical and operational planning of one sawmill, where bucking and sawing operations take place in the same business unit. This model does not take into account other processes, such as planing and drying.

To tackle the impact of different strategic design and planning approaches on the performance of lumber supply chains, Frayret *et al.* (2007) and D'Amours *et al.* (2006) proposed an agent-based experimental platform for modeling different lumber supply chain configurations. In that platform, different models exist to plan the sawmilling processes, the drying processes or the finishing processes.

In most of these models, very little attention is given to the modeling of the market with fluctuating prices, minimum contract volume and maximum market potential. They also assume yearly constant price and target volume throughput maximization.

Also, none of the models found consider the whole sequence of activities within the sawmill, from log supply to customer delivery into specific markets. Even fewer models integrating many sawmills with possible product transfer between mills.

### 2.3 S&OP

Sales & Operations Planning is the set of business processes and technologies that enables a business to respond effectively to demand and supply variability with insight into the optimal market deployment and most profitable supply chain mix. S&OP strategies help companies make "right-timed" planning decisions for the best combination of products, customers and markets (Muzumdar and Fontanella, 2006).

A typical planning period ranges from three months to three years and the process takes place in monthly cycles. The method involves activities among which are demand and supply planning. A successful demand plan requires the collection of different data to create forecasts that will consider updates by the sales team and product requirements, among other parameters. To plan supply, an operations plan must be generated that will take into consideration forecast changes as well as inventory shifts or capacity problems.

Through a case study in the oriented strand board industry, Feng, D'Amours et al. (2008) have formulated three supply chain management models: a multi-site supply chain based on S&OP which integrates planning of sales, production, distribution and procurement centrally, a multi-site sales-production planning based on S&OP in which only sales and production are planned centrally and finally a decoupled planning in which all functional planning is performed separately. These models were simulated with deterministic demand (Feng, D'Amours et al. 2008) and with a stochastic demand considering a rolling planning (Feng, D'Amours et al. 2010). Results showed that better performance can be achieved with the model based on S&OP process.

Critical inputs to the S&OP process are forecasts. Indeed, demand and price forecasting plays a determining role in the overall planning activities of a firm (Mentzer, Myers *et al.* 2007), especially in the forest industry since forest product prices and demand are well known for their fluctuations (Buongiorno and Balsiger 1977). Therefore, forest firms need efficient forecasting techniques to be better able to protect themselves against financial losses resulting from adverse market changes and to take advantage of market opportunities.

Difficulty in forecasting the exogenous variables in econometric models for forest products prompted forecasting analysts to use time series analysis, based exclusively on past behaviors of data series. We can represent in a rigorous way any systematic pattern existing in the development

of a price series and lead to forecasts as accurate as those produced by the best structural econometric models available.

Gomez, Love *et al.* (1999) considered an exponentially smoothed model and a non-parametric representation to forecast hardwood and softwood timber prices in Louisiana. The exponentially smoothed model allows forecasts to change continually with each new observation, but does not consider other information available beyond historical prices. However, the non-parametric model is more flexible for exploring relationships among variables. This method gives forecasts that are not related to a fixed parametric model since it estimates forecasts by smoothing data using a statistical function such as Kernel function. Therefore, data do not have to be explained by a parametric distribution unlike exponential smoothing.

## 3 PROPOSED MODEL FOR S&OP IN THE FOREST PRODUCTS INDUSTRY

With the specific characteristics of the lumber supply chain, mainly for first transformation mills, and with the production constraints and product selling price variability, we have developed a tactical planning model using linear programming. This model was used to assess the gains that could be obtained from a better integration of sales and operations. In our tests, we used historical selling price data and real sawmill production capacity and processes.

### 3.1 Mathematical model

Figure 2 illustrates a supply network of a multi-site softwood company. In such environment, a company usually has several mills $n$ ($n \in \mathbf{N}$) representing manufacturing plants and distribution centers which can be supplied by sources $s$ ($s \in \mathbf{S}$). Manufacturing plants are equipped with different types of production resources $e$ ($e \in \mathbf{E}$) involved in various activities $a$ ($a \in \mathbf{A}$). A node $n$ is supplied by $\mathbf{S}^n$ sources ($\mathbf{S}^n \subseteq \mathbf{S}$) and can execute $\mathbf{A}^n$ activities ($\mathbf{A}^n \subseteq \mathbf{A}$). $\mathbf{AS}^n \subseteq \mathbf{A}^n$ is the set of sawing activities which transforms logs into rough lumber. $\mathbf{K}$ are transport modes and $\mathbf{M}$ are the different markets where the products can be sold. $\mathbf{AP}^p$ ($\mathbf{AP}^p \subseteq \mathbf{A}$) are activities generating product $p$ ($p \in \mathbf{P}$) which can then be consumed by activities $\mathbf{AC}^p$ ($\mathbf{AC}^p \subseteq \mathbf{A}$). Each product $p$ can be moved by a transport mode $k$ ($k \in \mathbf{K}$) through roads $(n,n')$ ($(n,n') \in \mathbf{Ro}^{k,p}$) and can be finally sold to various markets $m$ ($m \in \mathbf{M}$). The planning horizon is $T$ periods, typically 52 weeks.

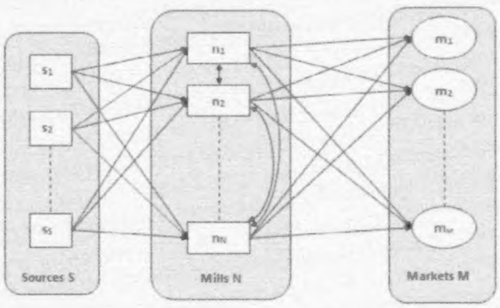


Figure 2 : Supply network of a multi-site softwood company

The table below lists the parameters and the variables of the model:

| | |
|---|---|
| $T$ | Number of periods $t$ included in the planning horizon |
| $\sigma_{n,n',k}$ | Transport delay from mill $n$ to $n'$ by a transport mode $k$ |
| $H_{e,n,t}$ | Capacity of resource type $e$ available at mill $n$ at period $t$ |
| $\delta_{e,a,n}$ | Resource capacity used by activity $a \in A^n$ |
| $\Phi^{con}_{a,p}$ $\Phi^{pro}_{a,p}$ | Quantity of product $p$ consumed [produced] by activity $a$ |
| $\alpha_{m,p,t}$ | Selling price of a product $p$ to a market $m$ at a period $t$ |
| $B^{min}$,$B^{max}$ | Minimum [maximum] percentage of the average lumber volume produced that has to be sold per period |
| $A^{\min}_{s,p,t}$, $A^{\max}_{s,p,t}$ | Minimum [maximum] supply of product $p$ from source $s$ in the period $t$ |
| $AT^{\min}_{s,p}$, $AT^{\max}_{s,p}$ | Minimum [maximum] supply of product $p$ from source $s$ over the planning horizon |
| $F_{s,p}$ | Percentage of product $p$ in the basket of products supplied from source $s$ |
| $C^{app}_{s,n,t}$ | Supply cost from source $s$ to node $n$ in the period $t$ (purchase + transport) |
| $C^{imm}_{n,p,t}$ | Inventory holding cost of product $p$ at mill $n$ in period $t$ |
| $C^{pro}_{a,n,t}$ | Production cost of activity $a \in A^n$ in the period $t$ (production cost) |
| $C^{tra}_{n,n',k,p,t}$ | Transport cost of a product p through a road $(n, n') \in Ro^{k,p}$ by a transport mode $k$ in the period $t$ |
| $D^{\min}_{m,p,t}$, $D^{\max}_{m,p,t}$ | Minimum [maximum] demand requirement of product $p$ for market $m$ in period $t$ |
| $I_{n,p,0}$ | Initial inventory of product $p$ at mill $n$ |
| $T_{n',n,k,p,1-\sigma_{n',n,k}}$ | Transported quantity of product $p$ through road $(n,n') \in Ro^{k,p}$ by transport mode $k$ at period $1-\sigma_{n',n,k}$ and received at period 1 |
| $T^{\max}_{n,n',k,t}$ | Maximum quantity that can be transported by transport mode $k$ through road $(n,n')$ at period $t$ |

Variables:

| | |
|---|---|
| $I_{n,p,t}$ | Inventory of product $p$ at mill $n$ at the end of period $t$ |
| $L_{a,n,t}$ | Number of times that the activity $a \in A^n$ is launched in period $t$ |
| $R_{s,n,t}$ | Quantity received from source $s$ to mill $n$ in period $t$ |
| $R_{s,n,p,t}$ | Quantity of product $p$ received from source $s$ to mill $n$ in period $t$ |
| $RT_{n,p,t}$ | Total quantity of product $p$ received at mill $n$ in period $t$ |
| $T_{n,n',k,p,t}$ | Quantity of product $p$ transported by mode $k$ through road $(n,n') \in Ro^{k,p}$ in period $t$ |
| $V_{n,m,p,t}$ | Quantity of product $p$ sold from mill $n$ to market $m$ at period $t$ |

| | |
|---|---|
| $V_{m,p,t}$ | Total quantity of product $p$ sold to market $m$ at period $t$ |
| $\Psi$ | Average volume of lumber produced per period |

The model objective is to maximize the gross margin. More specifically, as showed in equation 1, it considers sales revenue and the cost of supply, production, inventory and transportation.

Maximize

$$\sum_{t=1}^{T}\sum_{p\in P}\sum_{m\in M}\alpha_{m,p,t}V_{m,p,t}-\sum_{t=1}^{T}\sum_{n\in N}\sum_{s\in S^n}C^{app}_{s,n,t}R_{s,n,t}-\sum_{t=1}^{T}\sum_{n\in N}\sum_{a\in A^n}C^{pro}_{a,n,t}L_{a,n,t}-\sum_{t=1}^{T}\sum_{p\in P}\sum_{n\in N}C^{imm}_{n,p,t}I_{n,p,t}$$
$$-\sum_{t=1}^{T}\sum_{p\in P}\sum_{k\in K}\sum_{(n,n')\in Ro^{k,p}}C^{tra}_{n,n',k,p,t}T_{n,n',k,p,t} \tag{1}$$

Supply constraints are described in equation set (2). Equation (2.1) ensures that the products are supplied in the predefined proportion which depends on the source. Equation (2.2) is the total supply of a given product to a mill at time t. Equations (2.3) and (2.4) are supply limits from sources, per period and for the whole planning horizon.

$$R_{s,n,p,t}=F_{s,p}R_{s,n,t} \qquad \forall n\in N, p\in P, s\in S^n, t=1..T \tag{2.1}$$

$$RT_{n,p,t}=\sum_{s\in S^n}R_{s,n,p,t} \qquad \forall n\in N, p\in P, t=1..T \tag{2.2}$$

$$A^{\min}_{s,p,t}\le\sum_{n\in N}R_{s,n,p,t}\le A^{\max}_{s,p,t} \qquad \forall s\in S, p\in P, t=1..T \tag{2.3}$$

$$AT^{\min}_{s,p}\le\sum_{t=1}^{T}\sum_{n\in N}R_{s,n,p,t}\le AT^{\max}_{s,p} \qquad \forall s\in S, p\in P \tag{2.4}$$

Equation (3) fixes transportation limits for each transport mode through each road over a period.

$$\sum_{p\in P}T_{n,n',k,p,t}\le T^{\max}_{n,n',k,t} \qquad \forall (n,n',k)\in Ro^k, t=1..T \tag{3}$$

In equation (4.1), the quantity sold of each product $p$ from a mill $n$ to a specific market $m$ at a period $t$ is defined as the sum of all quantities of this product transported from the mill $n$ to the market $m$. Total quantities sold of product $p$ to each market are computed by equation (4.2). Quantities sold for each market $m$ must exceed a minimum demand to fulfill imposed by sales commitments to this market and can be limited by demand forecasts (equation (4.3)). Equations (4.4) and (4.5) set that the total quantities sold at any given period are also limited by minimum and maximum percentages of average lumber volume produced per period.

$$V_{n,m,p,t}=\sum_{k\in K}T_{n,m,k,p,t} \qquad \forall n\in N, m\in M, p\in P, t=1..T \tag{4.1}$$

$$V_{m,p,t}=\sum_{n\in N}V_{n,m,p,t} \qquad \forall m\in M, p\in P, t=1..T \tag{4.2}$$

$$D^{\min}_{m,p,t} \leq V_{m,p,t} \leq D^{\max}_{m,p,t} \qquad \forall m \in M, p \in P, t = 1..T \tag{4.3}$$

$$\Psi = \frac{\sum_{t=1}^{T} \sum_{p \in P} \sum_{n \in N} \sum_{a \in AS^n} \Phi^{pro}_{a,p} L_{a,n,t}}{T} \tag{4.4}$$

$$\Psi B^{\min} \leq \sum_{m \in M} \sum_{p \in P} V_{m,p,t} \leq \Psi B^{\max}, t = 1..T \tag{4.5}$$

Equation (5) imposes a yearly inventory cycle and resource capacities are considered in equation (6).

$$I_{n,p,T} = I_{n,p,0} \qquad \forall n \in N, p \in P \tag{5}$$

$$\sum_{a \in A^n} \delta_{e,a,n} L_{a,n,t} \leq H_{e,n,t} \qquad \forall (e,n) \in E \times N, t = 1..T \tag{6}$$

Equation (7) is for the product flow balance. The product inventory at mill $n$ at the end of period $t$ can be generalized as the inventory of the previous period, plus the quantity received at the current period (considered only for raw materials), minus the quantity consumed by production activities over the current period, plus quantity generated by production activities over the current period, plus the difference between incoming and outgoing flows over the current period. Finally, equation set (8) assures that all variables are non-negative.

$$\begin{aligned} I_{n,p,t} = {} & I_{n,p,t-1} + RT_{n,p,t} - \sum_{a \in AC^p} \Phi^{con}_{a,p} L_{n,a,t} + \sum_{a \in AP^p} \Phi^{pro}_{a,p} L_{n,a,t} \\ & + \sum_{k \in K} \left( \sum_{(n',n) \in Ro^{k,p}} T_{n',n,k,p,t-\sigma_{n',n,k}} - \sum_{(n,n'') \in Ro^{k,p}} T_{n,n'',k,p,t} \right) \qquad \forall n \in N, p \in P, t = 1..T \end{aligned} \tag{7}$$

$$V_{n,m,p,t}, V_{m,p,t}, L_{a,n,t}, R_{s,n,t}, R_{s,n,p,t}, RT_{n,p,t}, I_{n,p,t}, T_{n,n',k,p,t} \geq 0 \qquad \forall a,s,n,m,p,t,(n,n',k) \tag{8}$$

## 4 THE CASE

We studied a sub network of sawmills owned by a single company, taking two of their mills in the province of Quebec, Canada. Focusing mainly on the effect of selling price on planning of operations at the mills, we have used a single source for the logs and one general market to sell the dry planed lumber (see Figure 3).

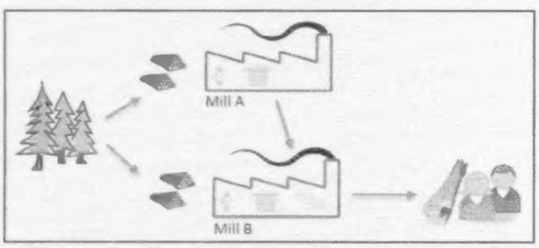


Figure 3 : Sawmill network with two mills

Both mills have sawing and drying capacity, but only the mill at Mill B can plane the lumber. Therefore, all lumber must be moved to Mill B to be planed. Also, Mill B has 60% of the overall drying capacity, so part of the lumber from Mill A goes directly to Mill B to be dried after the sawing operation. Both mills are close by and only 25km is driven to move the lumber from Mill A to Mill B.

It is assumed that there is a one-period delay (one week) between each production stage (sawing-drying-planing) and a one-period delay for the transportation between the mills and the market.

From the logs, 45 different lumber products are generated, 20% of which represent 64% of the produced volume (35% of the number of lumber products represent 80% of the produced volume). The figure below shows the proportion of dimensions after the sawing process.

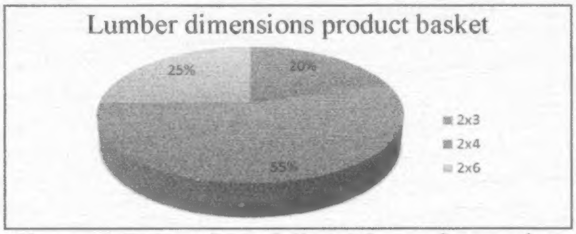


Figure 4: Proportion of dimensions after sawing

As the products sold from the mill are lumber commodity products, there is no limit on the maximum volume from each of these products that can be sold on the market. The limit is thus fixed by the production capacity and availability of the logs.

Tactical production planning models consider initial inventory but most of them do not restrain ending inventory. The problem with these models is they usually give solutions with zero ending inventories because such inventories increase inventory holding cost without increasing the revenue. This end inventory effect is often disregarded as it typically appends in the far future for tactical planning models, but we are unaware of any papers that actually study this end inventory effect. In our experiments, we have thus included a constraint stating that end inventory must equal starting inventory, as our model considered the planning over a year. Part of the decision is thus the targeted inventory level required, including the initial inventory, to achieve the highest profitability. In this context, the initial inventory is not an input data but rather a decision.

Because of the log procurement process, there is no flexibility in the sawing process: we have considered an average log yielding an average product basket. Therefore, period after period, the same rough lumber is available to be dried and planed. In such context, part of the increased gross margin is made by holding some items in stock so that they can be sold at a later time when the price for them is higher. On the other hand, the higher the holding cost, the less interesting it is to keep a product in stock to increase the revenue at a later time. The determination of item holding costs thus plays an important role and has a direct impact on the proposed solution. As our model assumes a fixed cost per unit in stock per period, we have used a holding cost for the dry planed lumber of 1% based on the average yearly product price of the dry planed lumber. For the green rough, dry rough and planed green, we used a holding cost of respectively 80%, 85% and 95% of the dry planed holding cost.

## 4.1 Selling price

To assess the potential gains, we made two plans. The first one reflects the current mindset of how sawmills plan their production: it does not change in time during the year and as such, the mills produce based solely on a push principle, pushing products through the mills regardless of the products demand and selling price. We call that plan the *stable plan*. The second plan takes into consideration selling price fluctuation that, according to the company, follows seasonality patterns. We call that plan the *S&OP plan*. In order to make that plan, we first had to compute seasonal indices.

In classical decomposition, seasonal indices are the variations around an average, variation that repeats on a yearly basis (Makridakis *et al*, 1998). Seasonal indices can be expressed as additive or multiplicative values. Additive indices are the difference between the trend and the actual value whereas multiplicative indices are the ratio of the trend to the actual value. Looking at selling prices, we expect the amount to fluctuate during the year proportionally to the average price level. So if we see an increase in the average selling price, the seasonal fluctuation around that average price will also increase and not stay constant. Seasonal indices for lumber selling prices are thus multiplicative.

We made our study looking at the selling prices on the Great Lakes market for 14 key products of the company. These products are all grade #1&2, dimensions 2X3, 2X4 and 2X6 with length varying from 8 to 16 feet. The table below lists these products.

| #1&2 GL | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2X3 | | | | 2X4 | | | | | 2X6 | | | | |
| 10' | 12' | 14' | 16' | 8' | 10' | 12' | 14' | 16' | 8' | 10' | 12' | 14' | 16' |

Table 1: 14 key products of the company

As the price is distinct for each product, we looked at the data for each product individually. For example, the blue line in the figure au-dessous shows about 12 years (651 weeks) of selling price value of lumber product P1 from 2010 to 2012.

The computation of the actual indices requires the trend to be extracted. We did so using a 52-week double moving average (red line in Figure 5 au-dessous). The resulting 52 seasonal indices of lumber product P1 for each year from 2001 to 2011 are charted in Figure 6.


Figure 5 : Weekly selling price of lumber product P1 and its moving average

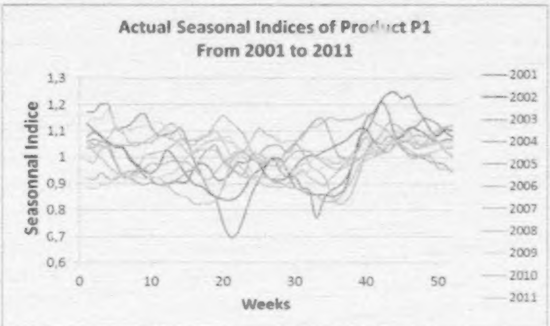


Figure 6 : Actual seasonal indices from 2001 to 2011 for product P1

## 4.2 Potential gain

Seasonal indices are used in the model to compute the S&OP plan. To assess the gain, each plan (S&OP and stable) has to be evaluated and compared. A production/sales plan can be evaluated for any given year by computing the revenue earned from that plan using that year's real product prices and by subtracting the costs of running that plan. The potential gain is then obtained by comparing the plan when the mill produces using a push principle (the stable plan) and when it produces to maximize the gross margin considering the average seasonal indices (the S&OP plan).

Using the actual selling price data of a given year to compute the seasonal indices and then using these indices to generate the S&OP plan and evaluating it for that same year would introduce a bias. To avoid that bias, when generating the S&OP plan to evaluate it for a given year, we remove that year's seasonal indices when computing the average indices used in the model that generated the plan.

For each year from 2002 to 2011, we evaluated the two plans and computed the gross margin increase of the S&OP plan relative to the stable plan (in percentage of revenue). Results are shown in Figure 7. It can be seen that for every year, the S&OP plan is always better than the stable plan, on average by 1,47%.


Figure 7 : Gross margin increase, S&OP plan VS stable plan

As mentioned earlier in Section 4, it was not possible in the context of the studied company to change the log replenishment and as such, the sawing process always yields the same product basket and is considered stable. Because of this, there are a few means used by the model to plan the selling of a product when it is most profitable. Besides the planing and drying plan, a strategy used by the model is to play with inventory levels. Figure 8 shows the variation in inventory levels of the finished products, aggregated by dimensions. According to the company, these stock levels are acceptable, both from a financial and from an operational perspective.

In computing the seasonal indices, many years were used, some quite far from the year tested. Moreover, market experts were not considered in computing these indices. So it could have been the case that for some years, a reduction of the gross margin would be seen rather than an increase. Nevertheless, the method revealed a positive increase for each year, showing there is a low risk of planning according to seasonal indices, even without expert knowledge of the market.

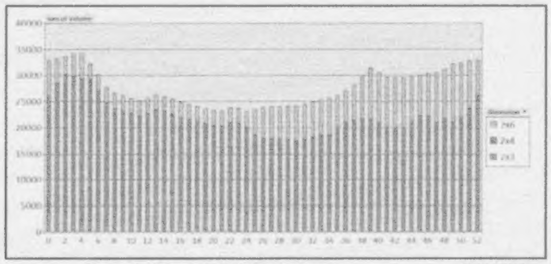

Figure 8 : Stock level of finished products, S&OP plan

## 5 CONCLUSION

Our study showed that it is always better to have a plan that adapts to fluctuating selling prices in order to capture possible revenue increase. In our case, the gross margin could be increased on average by 1,47%. We think this percentage is pessimistic as no advanced forecast methodology was used in determining seasonal indices for a given year. In real life and with the knowledge of the market, it would be possible to perform more accurate price forecasting for the year to come.

Since for both the stable plan and the S&OP plan the same products are sold throughout the year, the gross margin increase is only a consequence of shifting in time the finishing / selling of the products. The cost increase in the S&OP plan is a result of increased inventory. With the constraint that the sales volume must still be fairly constant throughout the year, we showed that by doing so it is possible to keep the inventory at a level that is acceptable to the company. The sales and operations plans obtained by the model are compatible with current company practice.

In our study, the stable plan was made as a base case and used as a reference for comparison to the S&OP plan. Typically, mill drying, finishing and selling plan are not that stable, but sawmills do not plan their production much in advance, even less according to forecasted selling prices. The use of a model like the one presented in this paper can help sawmills make better provision to increase product revenue while taking into consideration production and inventory constraints.

At project start, company management and directors were skeptical about the possibility of making any gains as production capacity was already being used at 100%. With these results, the company is changing its mind set and is now looking into ways of implementing S&OP tactical planning.

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